

Scaling with no phase transition

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(20 December 1994)

Abstract

The observation of scaling relations in ultra-relativistic nuclear collisions would not by itself signal that the hot matter produced in these collisions has passed through a phase transition.

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One of the goals of studying the hot matter produced in ultra-relativistic heavy ion collisions is to find a signal that the produced matter is a quark gluon plasma, or some other exotic phase of strongly-interacting matter, which is separated from low-temperature hot nuclear matter by a phase transition. One technique which has been explored is the construction of multi-particle correlation functions such as scaled factorial moments (SFM) [1],

$$F_q = \frac{\langle n!/(n-q)! \rangle}{\langle n \rangle^q}, \quad (1)$$

where n is the number of particles in a given bin. The hope is that, because fluctuations typically have non-trivial behavior near phase transitions, the SFMs may also exhibit anomalous behavior near a phase transition.

Recently, Mohanty and Kataria [2] showed that, if the hot matter produced in an ultra-relativistic nuclear collision freezes out shortly after passing through a first- or second-order phase transition, the SFM data will obey a scaling law:

$$F_q \propto F_2^{(q-1)^{1.33}}. \quad (2)$$

They then claimed that the observation of this scaling would signal that the hot matter had frozen out shortly after passing through a phase transition. This scaling was previously demonstrated (for the case of a second-order phase transition only) by Hwa and collaborators [3], who claimed that it would indicate passage through a second-order phase transition. However, neither claim is true, as the scaling can be produced even if the hot matter never passes through a phase transition.

Both groups worked in the context of a Ginzburg-Landau mean field theory of phase transitions [4]. In their calculations, the free energy density of the hot matter is

$$F[\phi] = a'(T - T_c) |\phi|^2 + b |\phi|^4 + c |\phi|^6, \quad (3)$$

where ϕ is the order parameter for the phase transition. The phase transition is second-order for $b > 0$ and first-order for $b < 0$.

Mohanty and Kataria demonstrated that, within this Ginzburg-Landau mean field theory, scaling of SFM data will occur if the hot matter freezes out shortly after passing through a phase transition, whether first- or second-order. However, they neglected to show that it is necessary for the matter to pass through the phase transition for the scaling to occur. For example, the scaling may be observed if there is a phase transition at finite temperature T_c but infinite (or very high) energy density, so that the system approaches T_c from below but never crosses into the high-temperature phase. Scaling may also be observed if the equation of state of the hot matter exhibits a fast but smooth transition, where the coefficient of the quadratic term becomes small but never changes sign so that there is no phase transition. Thus, the mere observation of scaling does not indicate that the hot matter has passed through a phase transition.

ACKNOWLEDGMENTS

This work was supported in part by the Natural Sciences and Engineering Research Council of Canada, and in part by the FCAR fund of the Québec government.

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